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Temperature gradients in diode-pumped alkali lasers

Charles Fox and Glen Perram

Localized heating in diode-pumped alkali lasers induces spatial variations in metal vapor density, leading to a reduction in laser power.

The quest for a high-power, electrically driven laser with excellent thermal management, lightweight packaging, and high brightness for tactical military applications may be realized with the advent of the diode-pumped alkali laser (DPAL). Pumping a gas-phase medium with large diode arrays combines the best features of electrically driven lasers with the inherent thermal management advantages of a gas laser. Indeed, DPALs offer significant promise for high-average-power-performance.[1] The radiation from bars or stacks of diode lasers is absorbed by atomic potassium, rubidium, or cesium. Collision-induced energy transfer populates the upper laser level, and lasing is achieved in the near-IR on the D_1 (pump) line. A rubidium laser pumped by a 1.28kW diode stack with a 0.35nm spectral bandwidth recently achieved 145W average power.[2] More than 70% of the diode pump power can be converted to the DPAL power when the pump and resonator volumes are mode-matched, and a high fraction of the incident pump radiation is absorbed.[3] Hybrid DPAL systems combine efficient diode pumping with the good beam quality and thermal characteristics of gas lasers.

DPAL quantum efficiency is very high (95–98%) and collisional quenching is typically negligible, offering the potential for low waste heat loads. However, cycling of atoms by the pump beam can be $>10^9$photons/atom-s. The energy of the spin-orbit splitting is lost to waste heat in each cycle. Several recent DPAL demonstrations by us and others have observed negative impacts associated with gain medium heating, and the community is beginning to develop slow-flowing gas handling systems. We have found no significant kinetic problems associated with gas heating.[4] It is more likely that localized heating induces a spatial variation in alkali atom concentration. A corresponding reduction in pump absorbance would directly impact output power. Here, we describe work showing that pump-beam heating induces a radial distribution of absorbance and establishes a significant temperature rise within the pumped volume.

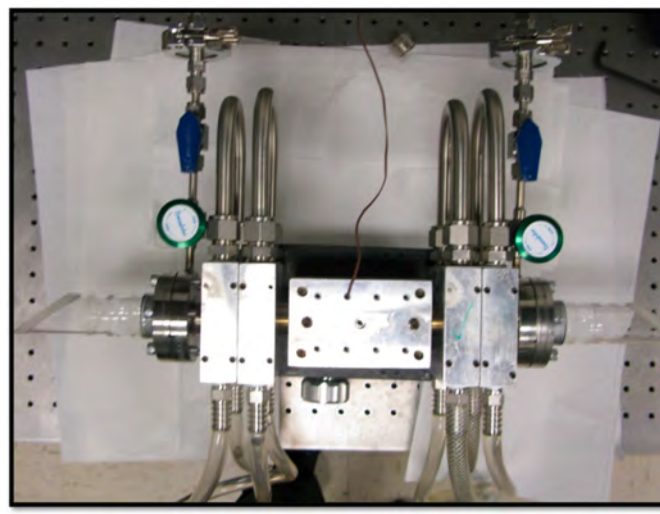

Figure 1. *Diode-pumped alkali metal vapor laser (DPAL) heat pipe for a cesium laser.*

Most DPAL systems have used static glass cells for the gain medium. We use a heat pipe with Brewster-angle windows, as shown in Figure 1. We use a $0.8W/cm^2$ pump laser at the D_1 frequency to heat the medium in a $T = 50-100°C$ cesium heat pipe with nitrogen (5Torr) to artificially increase the heat load. The ends of the heat pipe are held at 15°C to avoid deposits of cesium from forming on the windows. These colder regions are often referred to as a condenser and the center an evaporator as the gas medium changes phase in these two distinct regions. The heat pipe contains a stainless steel wire mesh of 150×150 strands per inch rolled four times on the inner wall of the heat pipe, often called the wick. The wick is responsible for the capillary pumping of cesium from the condenser to the evaporator.

We use a $31\mu W/cm^2$ diode laser to probe the spectral absorbance of the cesium cell on the D_2 (laser) transition with radial spatial resolution of 2mm. The frequency of the probe

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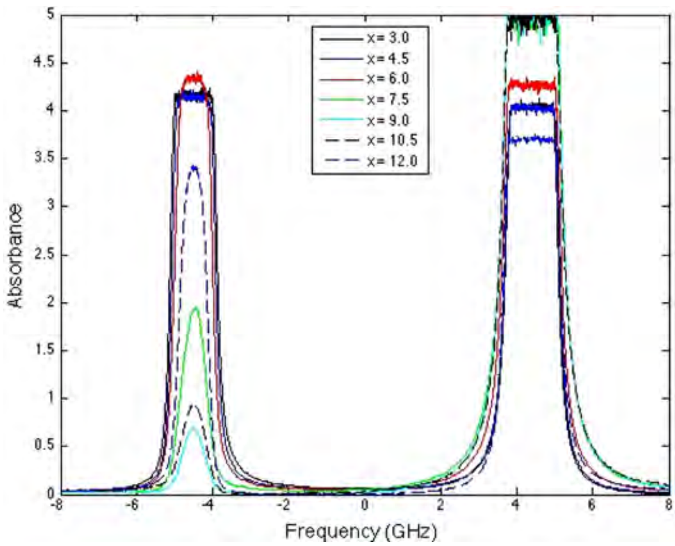

Figure 2. *Probe laser absorption spectra at various radial positions (x).*

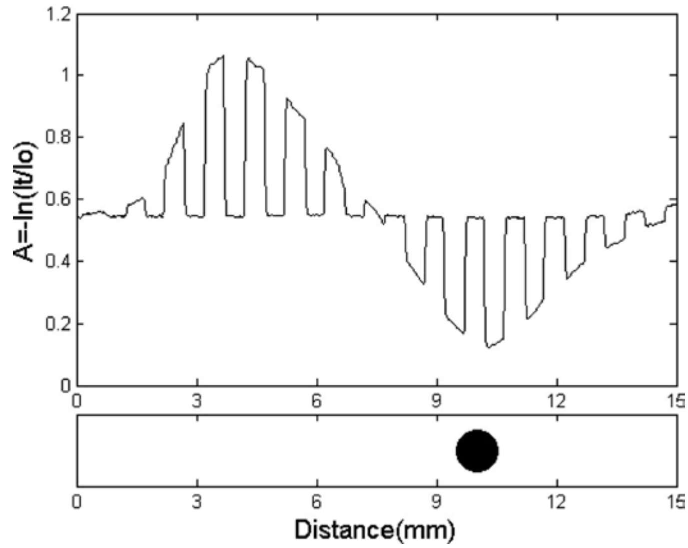

Figure 3. *Spatially resolved absorbance,* $A = -ln(I_t/I_0)$*, at –2GHz detuning.*

laser is scanned by 20GHz across the optically thick hyperfine structure, revealing absorbances of 1–5 (see Figure 2). The larger hypefine splitting in the ground state of 9192.6MHz is easily resolved. The pump beam is located off-axis at x=10mm. The spectral features are modified by several effects: depopulation of the ground state ($F'' = 4$ component) by the pump laser; changes in the Doppler broadening due to local temperatures; and changes in the Lorentzian lineshape due to local variations in total number density. Spectral simulations of the lineshapes reveal spatially dependent alkali concentrations, temperature, and nitrogen concentrations.

The absorbance outside of the pumped volume is modulated by up to a factor of two when the pump beam is blocked, suggesting significant temperature gradients. Figure 3 shows the radial distribution of absorbance when the probe beam is detuned by 2GHz to the red side of the F''=2 hyperfine component. When the pump beam is blocked, the absorbance is independent of position. When the pump beam is active and displaced from the center of the pipe at x=10mm, the absorbance is reduced within the pump beam and enhanced by a factor of two outside of the pumped volume. Heating occurs within the pumped volume, reducing the local alkali concentration. Pump absorption is reduced, leading to lower DPAL output power. We have characterized the dependence of the temperature profiles on pump power, nitrogen pressure, and heat pipe temperature.

In summary, we have investigated heat loads in DPALs using a diode laser to probe the radial dependence of the absorbance. The absorbance outside of the pumped volume is modulated by up to a factor of two when the pump beam is blocked, suggesting significant temperature gradients that are detrimental. Ideal DPAL system performance can be restored by properly designing the alkali concentration in the presence of the heat load. We are now prepared to study temperature gradients in high-power DAPL devices.

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